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BIOLOGICAL CONTROL STUDIES WITH THE WESTERN PINE BEETLE

PROGRESS REPORT - 1929

by

H. L. PERSON
Bureau of Entomology

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SUMMARY

Studies in biological control were begun in 1928 on the Modoc National Forest in response to the need for a method of control more effective than the burning method now used. There is also need for a method that can be safely used during the summer months, especially where thorough clean-ups and maintenance control are desirable. The aim of the studies is to make control methods more effective and the results more permanent by protecting the important beneficial predators which are destroyed both by the burning method and to a smaller extent by the peeling and sun-curing method.

The ability of the predators to escape from unfavorable conditions because of their motility suggested the method of exposing the infested logs to unfavorable temperatures. The theory is that if unfavorable conditions were produced gradually the clerids, being motile, could move to a more favorable location and so escape, while the western pine beetle larvae, having practically no power of locomotion, would succumb.

In 1928 most of the work was concentrated on the comparative effects of exposure under different conditions on the broods of the western pine beetle and the clerid. In 1929 studies were continued, with emphasis on the relation between air temperatures and bark temperatures and the effect of known bark temperatures on the mortality of D.brevicomis and its principal predator.

As a result of two seasons' work on this study the following conclusions appear to be justified:

1. Bark temperatures on the top and upper sides of an infested log exposed to direct sunlight were found to run well above the point known to cause mortality in D.brevicomis broods (Chart 6).

A. At an air temperature of 97° F. a bark temperature of 122° was reached. Bark temperatures were found to run as much as 32° F. above air temperature (Chart 1).

B. The bark temperatures reached depend on a number of factors, including position on the log, air temperature, exposure and slope, bark thickness, and moisture content of the inner bark. It was found that the difference between air temperature and bark temperature was much less in the bark of a fresh green log than in the bark of an infested log which had lost a considerable amount of its moisture (Chart 7). (Refer to Beal's[1] report for a more complete treatment of this point.)

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[1]Beal, J.A. Insect Increase in Logging Operations in Western Yellow Pine; Progress Report; Jan. 15, 1930

C. Since some brood mortality of D.brevicomis occurs at bark temperatures between 100° and 115° F., and since practically 100 per cent mortality occurs at bark temperatures over 115°, the mortality can be estimated for different bark temperatures.

2. The actual mortality of D.brevicomis in exposed logs agrees quite closely with what would be expected on the basis of the studies on fatal temperatures by Miller and Patterson.

Only a small percentage of D.brevicomis survived on the tops of logs favorably exposed. No mortality occurred in the one log exposed on a rather steep northeast slope in a cool location. (Chart 9)

3. No mortality of clerids was noted, even where the highest bark temperatures were recorded.

Since living clerid larvae were found in bark in which 100 per cent of the D.brevicomis were killed, it is probable that clerid larvae are not only able to escape from unfavorable conditions, but are also able to withstand temperatures which are fatal to D.brevicomis (Chart 10).

4. The mortality of D.brevicomis on the sides and bottom of exposed logs is apparently much higher than in infested trees which are left standing, probably because of less favorable moisture and temperature conditions and because of the concentration of clerids which are driven from the upper parts of the logs by high temperatures.

5. This method of control would be applicable only on the summer generation trees in which clerids are fairly abundant. Its effective use would also be restricted to areas with fairly open stands and with gentle slopes or favorable exposures. Such conditions are found over large yellow pine areas in southern Oregon and northern California.

6. It is suggested that this project be continued on a scale sufficiently large to determine more definitely the possibilities, limitations and approximate costs of this method.

The Timber Mountain area is proposed for such an experiment, and a survey of the area will be made during 1930 to determine the degree of isolation, size of the timbered area, and amount of infestation on the area.

BIOLOGICAL CONTROL STUDIES WITH THE WESTERN PINE BEETLE
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INTRODUCTION

Studies have been carried on during the past two years on the Modoc National Forest in an attempt to develop some method of control of the western pine beetle that would be more satisfactory than our present methods. The principal disadvantage of the usual method is that all the beneficial parasites and predators are destroyed with the destructive bark beetles. This is probably one reason why the results obtained by artificial control are usually short-lived. In the biological control studies an attempt is being made to develop some method of control, by exposure instead of by burning, which will kill a large percentage of the bark beetles without injury to most of the predators. In this work little attention has been paid to parasites, because it has been found that they are of little importance in the natural control of the western pine beetle.

The basis for these studies lies in the much greater motility of clerids, as compared to the western pine beetle, in the larval stage. This makes it possible for the predators to escape from conditions that prove fatal to the western pine beetle. On the basis of studies already conducted it appears that predators are also able to withstand higher temperatures than the western pine beetle.

The method used in these studies is to fell the infested trees in more or less exposed positions, and depend upon high bark temperatures and unfavorable moisture conditions to destroy the bark beetles without killing many of the beneficial predators. The bark is not peeled, as in the sun-curing method, but left intact on the trunk. It is obvious that this method is applicable only during periods of fairly high air temperatures. This, together with the fact that only in the first summer generation trees is the most important predator, Enoclerus lecontei, abundant, limits the use of this method of control to the summer months.

In the 1928 studies[2] one tree was studied in considerable detail, and supplementary data were obtained from a number of other trees. On the basis of this work it was tentatively concluded that

1. Felled trees or logs may be exposed under field conditions so that a high percentage of the bark beetles are killed without serious loss of the beneficial clerids. On the one tree studied intensively the mortality of the western pine beetle was 70 per cent above normal, while the mortality of the clerids was not more than 10 per cent above normal.

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[2]Person, Hubert L. Western Pine Beetle Biological Studies, Modoc National Forest, Season of 1928; June 1, 1929

2. The mortality of D.brevicomis varies on different sides of the logs, due to differences in temperature and moisture and to the concentration of the clerids.

3. The low emergence from the sides and bottoms of exposed logs indicates that the mortality, even where high temperature is not a factor, is much higher than on trees left standing.

It was also concluded that further studies were needed to determine particularly the relation between air temperature and bark temperature on different log positions, the effect of slope, duration of exposure and stage of brood.

It was planned to cover all these points during 1939, but because of the decided drop in the infestation it was not possible to find sufficient infested material near the Buck Creek Station, and so the plan of work was greatly reduced. The principal point covered was the relation between air temperatures and bark temperatures on different log positions, though some data were obtained on the effect of these temperatures on broods of D.brevicomis and the clerid, E. lecontei. The chief aim was to determine what air temperatures would result in fatal bark temperatures on the top and sides of exposed logs.

The study was conducted at the North Warner's field laboratory of the Bureau of Entomology at Buck Creek. The area is in the lower, pure yellow pine belt at an elevation of 5100 feet. The exposure is toward the southwest, though the site of the experiments is nearly level. Continuous records of temperature and humidity were taken by means of a hydrothermograph. These records are summarized in Plate 1.

Very few well-infested D.brevicomis trees were found in the vicinity of the station, and those found were too far from roads to be available; so the infested logs used in the temperature study were cut from a tree found in the Badger Springs unit of the Modoc area.

BARK TEMPERATURES AND BROOD MORTALITY IN INFESTED TREE MB-B.G.

Methods

The temperatures occurring on different sides of the log were determined by means of 12-inch laboratory thermometers with graduations in even degrees from 0 to 220° F. The method of inserting the bulb of the thermometer into the outer bark is as follows: By means of a brace and bit a hole 15 mm. in diameter was bored into the end of the log from a point about one inch deep in the sapwood and slanting outward, so that the hole extended through the outer sapwood and inner bark and to the center of the outer bark. The hole was bored so that the bulb of the thermometer could be inserted into the bark at a point about three or four inches in from the end of the log. (It was found by comparative tests that the bark temperatures at this distance in from the end of the log were within one degree Fahr. of the temperatures in the bark at the center of the log, obtained by using thermometers in holes bored tangentially through the bark.) After the hole was bored into the end of the log a hole 7 mm. in diameter was bored through a 15-mm. cork, which was then fitted into the opening of the hole. The thermometer was then pushed through the hole in the cork, which it fitted tightly, until the bulb was in the outer bark. By this method the inner part of the hole is effectively insulated from the outer air. The exposed part of the stem of the thermometer was protected from the sun's rays by a cardboard cylinder of small diameter which was covered with white paper.

The effect of temperature on the mortality of the western pine beetle and on the clerid was determined by making brood counts on sample bark areas before and after exposure, and by caging a large area of bark before and a similar area after exposure. The emergence from the caged bark was collected and the results from different samples compared. The sheet-metal type of rearing cage that was developed last year was used. Unfortunately there was leakage of D.brevicomis adults from some of the cages, due to lack of care in replacing the cotton "gasket" used around the mouth of the collecting jar after collections were made. Because of this the results from the caged bark samples could not be used in most cases except for E. lecontei records, since there was no leakage of the clerids.

On account of a lack of time and suitable material, temperature records were taken from only one infested tree, MB-B.G., from the Badger Unit of the Modoc National Forest. This tree was one of a group of five medium-sized trees well infested with the main summer generation brood of D.brevicomis. It was 20 inches in diameter and 100 feet in height. When felled on August 1 it was completely infested with a good brood of western pine beetle larvae and pupae, except for 20 feet at the top which contained Ips oregoni broods. It was a mature Class 4 tree with medium-thin bark, approximately $\frac{5}{8}$" in thickness. Two logs, each four feet in length and approximately 18 to 20 inches in diameter were cut from the lower trunk of this tree and moved to Buck Creek for use in the temperature study.

One of the logs was laid flat on the ground in a north and south direction and the other was set upright. Both were exposed to direct sunlight throughout the day except for the period between 3 and 5 p.m., when some shade was cast on them by a nearby tree. Thermometers were installed in the logs according to the method already described. Four were used in the log lying on the ground--one in the top, one in the bottom and one in each side of the south end. On the standing log thermometers were used only on the north and south exposures of the upper end.

All temperature records were taken at 8 a.m. and at 1 and 5 p.m. daily for a twelve-day period, August 2 to 13 inclusive.

Study of infested log lying on the ground

The results have been summarized in a series of charts.

The bark temperatures at the different log positions are shown in Charts 1-3. Chart 1 gives a comparison between air temperatures and bark temperatures at the different positions at 8 a.m. The relations are about what would be expected at that time of day, with the highest temperature on the east side because of the directness of the sun's rays, the lowest temperatures on the west side and bottom, and intermediate temperatures on the top. The unexpected part of the result is the amount of difference between the air temperature and the bark temperature on the east side of the log. This difference varies from a minimum of 18° F. on August 8 to a maximum of 32° on August 13. This is the largest deviation from air temperature that was found in these studies. It may be explained, in part at least, by the small angle of incidence of the sun's rays on the east side at that time of day, and by the small amount of radiation from the bark surface which would result from a lack of air movement. There was usually very little if any wind in the morning until about ten o'clock.

Some inconsistencies are evident in the deviation of bark temperatures from air temperatures. These differences are probably due to a number of factors, such as cloudiness or haziness; air movements and rate of rise of the air temperatures.

Although the temperatures reached on the east side of the log are higher than the air temperatures and bark temperatures on the other sides of the log, they are still too low to cause mortality of D.brevicomis broods. Hourly records were not taken, but it seems probable that fatal temperatures might be reached at about 10 or 11 a.m. and continue until past noon. This point can be checked next season by taking hourly readings on a few logs. It is noteworthy that at the time of year when this experiment was conducted, the bark temperature on the bottom of the log was high enough to allow development of broods even at 8 a.m.

Chart 2 gives the temperature curves for this log at 1 p.m. As would be expected, the highest temperatures were found on the top of the log and the lowest on the bottom. The temperatures on both east and west sides were well above air temperatures, and on the east side temperatures reached were high enough (100° to 107° F.) to be fatal to a small percentage of the D.brevicomis broods if maintained for several hours.

Since practically 100 per cent of the D.brevicomis broods are killed by an exposure of one hour at 118° F., it is obvious that very few of the broods would survive the temperatures on top of the log, which reached a maximum of 122° F. on August 13. The difference between air temperatures and bark temperatures on top of the log are very marked, the bark temperatures ranging consistently between 25 and 35 degrees higher. Although these differences are not as great as between air temperatures and east side bark temperatures at 8 a.m., they are much more important because of the high temperatures reached. The smaller departure from air temperature found on the top at 1 p.m. than on the east side at 8 a.m may be explained by the greater angle of incidence of the sun's rays and the greater air movement at 1 p.m.

In Chart 3 the bark and air temperatures at 5 p.m. are shown. There is a noticeable grouping of the temperatures, with very little deviation from the air temperature. The west side gives the highest bark temperatures and the bottom the lowest, while the top and east sides are intermediate. This chart does not represent normal conditions for full sunlight because a large tree about 100 feet southwest of the log cast a rather heavy shade after about 3 p.m. In full sunlight we should expect the west side of the log to reach temperatures that would be fatal to D.brevicomis broods.

Temperatures fatal to D.brevicomis

Miller and Patterson[3] have determined quite accurately what bark temperatures are fatal to D.brevicomis. On the basis of their conclusions it is assumed that bark temperatures above 115° F. will prove fatal to advanced broods of this beetle if continued for over one hour. Prolonged exposure to temperatures between 100 and 115° F. will result in a mortality of from 40 to 90 per cent of the broods. Chart 6 was prepared to show under what conditions of air temperature and exposure mortality of D.brevicomis might be expected. The curves were projected arbitrarily on the basis of the three temperature readings taken at 8 a.m. and at 1 and 5 p.m. They should be checked with hourly readings if this work is continued next season. Again referring to Chart 6, we find that at an air temperature of 85° the bark on only the top of the log reached a temperature high enough to result in any mortality of the broods. The maximum was 110° F., while a temperature of 108 was probably maintained for more than two hours. This would probably result in only a small percentage of mortality. At an air temperature of 90° F. the bark on top of the log reached a temperature of 117°, which would result in a high percentage of mortality, and bark on the east side reached a temperature of 104° F., which would result in very little, if any, mortality.

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[3] Ms. in course of preparation by Miller

With an air temperature of 97° F. at 1 p.m. the bark on top of the log reached a temperature of 122° F., which should result in 100% mortality; and the bark on the east side reached a temperature of about 106° F., temperatures over 106° being maintained long enough to result in some mortality.

Theoretically, then, 100 per cent of the D.brevicomis brood on top of the log and a small percentage of the brood on the east side of the log should have been killed by the high temperature. The brood in sample areas of the log used in the temperature study was examined before and after exposure to determine the actual effect of the exposure.

D.brevicomis brood reduction

It is not possible to determine the exact mortality because of the variability of the brood in different bark areas and because the dead brood after shriveling from drying cannot all be found when making the brood counts. Approximate figures were obtained by shaving up comparable bark samples before and after exposure from all log positions.

The results are summarized in Chart 8 and compared with the results from other exposed logs in Chart 9. The stage of the brood and the number in each stage both before and after exposure are also shown (Chart 8). Before exposure the bark contained heavy broods of living D.brevicomis--239, 179, 210 and 157 per square foot on the top, bottom, east and west sides respectively. The variability in the amount of brood on the different sides is noticeable. After the two weeks' exposure the living broods were reduced to 21 on the top, a reduction of 91%; 61 on the bottom, a reduction of 66%; 61 on the east, a reduction of 71%; and 81 on the west, a reduction of 41%. Although these percentages are only approximations because of the variability in the broods in different parts of the same side, they indicate that the highest mortality was on the top, as would be expected because of the high temperatures reached, lowest on the west side and bottom and intermediate on the east side.

In making the counts some of the dead brood were found; and although the number found was probably too small to determine the percentage of living and dead, it does give some idea of the much greater mortality found on top of the log. Of the 94 D.brevicomis found on top of the log after exposure, 63 or 75% were dead, and of the 80 found on the east side 19 or 24% were dead. Most of these were probably killed by high temperatures, and the actual mortality was probably considerably higher. On the bottom, after exposure, five of the 56 found or 8.2% were dead, and two of the 83 found on the west side, or 2.4% were dead. Since no fatal temperatures were found on the west side or bottom of the log, the dead larvae and pupae found probably died as the result of unfavorable moisture conditions or were killed by predators.

Effect of high bark temperatures on N.lecontei larvae

No work has been done toward determining the fatal temperatures for this clerid except indirectly as a part of this study. A comparison of the number of clerids per square foot of bark before and after exposure was obtained by means of the brood counts made before and after exposure and by means of the collections from bark samples caged before and after exposure. In Chart 8 the brood counts and the collections from the caged bark are shown by exposures. In the four square feet of bark that was shaved up no dead clerids were found. It is particularly significant that of the two square feet of bark from the top of the log--one of which was shaved up and the other caged after the log was exposed--one still contained four living clerids and the other five. No dead clerids were found in either piece. Since over 75% of the D.brevicomis brood in the same bark was killed by the high temperatures, it may be assumed that clerid larvae are not only able to escape from bark areas with high temperatures as a result of their motility, but they are also able to withstand temperatures which prove fatal to D.brevicomis.

The above results agree with those for the 1928 studies in that in no case was any evidence found of clerid mortality as a result of high temperatures.

It is noteworthy that in the caged bark, although the average number of clerids per square foot is nearly the same before and after exposure (8 and 7 respectively), the number is smaller after than before exposure on the top, where the temperatures were highest, and slightly larger after exposure on the bottom and west side, where no high temperatures were recorded. On the top the bark examined before exposure contained 17 clerids and the bark caged after exposure only five, whereas on both the bottom and west side there were six before and nine after exposure. On the east side the same number (four) was found before and after exposure. This also agrees with the results of the 1928 studies, which indicated a definite migration of some of the clerid larvae from the hotter to the cooler parts of exposed logs.

The bark counts made after exposure by shaving up bark samples show reductions on all four sides of the log. This is probably the result of letting the bark used lie around for a day or two after it was peeled from the log, before it was shaved up for the bark counts. This would cause many of the clerids to leave the bark because of the rapid drying. The bark used for rearing in the metal cages could be put into the cages immediately after it was peeled from the log, so that no loss of clerids could occur.

In any case a reduction in the number of clerids in a log resulting from exposure does not represent mortality, as it does in the case of the D.brevicomis brood, because many of the mature clerid larvae normally migrate to the ground to pupate. Since no dead clerid larvae have been found in any of the bark sections examined, either in 1928 or 1929, we may assume that clerid mortality as a result of exposure is practically negligible.

Study of standing infested log

One of the infested logs taken from Tree 83-S.W. was used for studying the relation between air temperature and bark temperatures on a standing log, and the effect of the temperatures on the broods. The D.brevicomis brood, at the time the tree was felled, consisted mostly of large larvae and pupae with a few new adults. The log was set on end in an open, exposed, fairly level location near the log used in the other temperature study. It was exposed to full sunlight except for the period between 3 and 5 p.m.

Two thermometers were used, one on the north exposure and the other on the south exposure at the upper end of the log. They were installed according to the method already described. The effect of temperatures on the broods was determined by comparative counts before and after exposure.

Bark temperatures, north and south exposures

The results of the temperature study are presented in Charts 4 and 5. Chart 4 gives the temperatures at 8 a.m. and 5 p.m. for the bark on the north and south sides and also air temperatures. The relations are about what would be expected. The temperatures on the north side are low both in the morning and afternoon. The air temperatures average slightly higher than the bark on the south side at 8 a.m. and slightly lower at 5 p.m. No lethal temperatures were found at these hours.

Chart 5 gives the temperatures at 1 p.m. A very consistent relation is shown, with the temperature on the south side running about 10 to 12 degrees warmer than the air temperature and the temperatures on the north side about one or two degrees cooler.

Since the bark on the south side reached a temperature of nearly 110° F., some mortality among the D.brevicomis broods would be expected. This is an interesting point, since it indicates that there is at least a possibility of the bark on standing infested trees reaching temperatures fatal to the beetles. Since some shade is usually cast on the trunk during the middle of the day, fatal temperatures would occur only in trees with very small or one-sided crowns, in open situations.

Brood reduction in bark of standing log

Brood counts were made on bark samples taken from the north and south sides of the standing log after exposure, to determine the effect of high temperatures on the broods and whether mortality occurred.

On the south side a total of 76 D.brevicomis were found, 49 living and 27, or 35%, dead. It is very probable that most of the dead larvae found were killed by high temperatures. On the north side the living brood was 48, only one less than on the south side, but no dead brood was found. It is assumed that the small brood found on the north side was the result of natural variability in different samples, not of high temperatures.

Most of the clerids were evidently driven from the log by unfavorable conditions, probably dryness as well as high temperatures. Only one living clerid was found and no dead ones.

The results of this experiment with a standing log are obviously of little practical value in connection with biological control. They are of interest, however, for comparison with the results of a log lying on the ground, and also because they show the possibility of temperatures fatal to D.brevicomis broods in standing trees.

BARK TEMPERATURES OF A GREEN LOG

Bark temperatures were taken on one green freshly-cut log in order to compare the bark temperatures reached with those from infested logs.

The log used was about 18 inches in diameter, with bark about ½" in thickness, or about the same as the bark on the infested log studied. The log was laid on the ground with the ends facing north and south, in the same location used later for the infested log. The thermometers were installed as already described. Records were taken three times daily, at 8 a.m., 1 p.m. and 5 p.m., from the 18th to the 22nd and again on July 29.

Only the results from the one o'clock reading were summarized; they are shown in Chart 7. For comparison with the infested log temperatures see Chart 2. The general trend is the same in both cases, but there is a striking difference in the departure from air temperatures observed on the top of the log in the two cases. The bark on top of the infested log ranged from 25 to 28 degrees higher than air temperature, whereas the bark on top of the green log only ranged between 8 and 13 degrees higher.

Part of this difference may be due to the higher air temperatures experienced while the infested log was being exposed; but most of it must be due to the difference in the moisture content of the two logs, the higher moisture content in the green log acting as a heat regulator for the bark.

Beal has studied the differences in bark temperatures between fresh green logs and trees and infested or partially dried logs in considerably more detail. His work is covered in a recent report, "Insect Damage in Logging Operations in Western Yellow Pine".

The low stage of the infestation on the North Warner area during 1929 made it almost impossible to find trees suitable for this part of the study. However, three trees were located and felled and bark counts made before and after exposure in order to obtain data to supplement the records from the tree on which the temperature study was made. None of the three trees was entirely satisfactory, for both the Crom's Mill and Lassen Creek trees were only partially infested with the western pine beetle, the balance containing Ips D.monticolae and buprestids. The Buck Creek tree was on a northeast exposure, so that fatal temperatures were not reached on any part of the tree. However, data of some value were obtained from these trees and will be included here.

Tree N 1 - Crom's Mill Area

This was one of a group of three large trees infested with the first main 1929 generation of D.brevicomis. It was 34 inches in diameter breast high and 110 feet in height. The site was nearly level with a slight slope toward the southwest. The tree after being felled was fully exposed during the middle of the day, but shaded by nearby trees in the morning and late afternoon.

When felled on July 27 it was found to be infested with Ips emarginatus and D.monticolae, particularly on the south side, as well as with D.brevicomis. After the limbs were trimmed so as to leave the trunk exposed, 15 square feet of infested bark was taken from a strip completely around the trunk, about 25 feet from the base. At the same time one square foot of bark was taken from each of the four sides--top, bottom, east and west--to be used for bark counts. The tree was felled in approximately a north and south direction. The records from the 15 square feet of bark placed in the metal cages were of no value in determining the D.brevicomis emergence because of the leakage previously noted. The four square feet of bark from the different sides were shaved up and brood counts made on July 27.

One week after the tree was felled another set of brood counts was made from samples similar to those taken before exposure. The results of both sets of counts are presented in Chart 10 and compared with the other trees studied in Chart 9. The bottom of the log was almost completely infested with Ips emarginatus, and so will not be considered further. Comparison of the counts before and after exposure shows a marked reduction in D.brevicomis broods on all the other sides, with very high mortality on top of the log. The square-foot sample taken from the top of the log before exposure contained 129 living D.brevicomis, and in a similar sample taken after exposure only 20 living and 48 dead D.brevicomis were found. This high mortality was undoubtedly the result largely of high temperatures, since no dead brood was found on the sides or bottom of this log. On the east and west sides the broods were evidently reduced from 58 to 38 and from 24 to 12 respectively during exposure, but no evidence of direct mortality from high temperatures was found.

The larvae of R.lecontei and of Temnochila virescens, a general predator, were slightly more abundant in the samples taken after exposure than in those taken before exposure. There was no evidence of any mortality of predators, even on top of the log.

Tree M 5 - Buck Creek Area

The next tree studied was 30 inches in diameter and 100 feet high, located near Buck Creek on a fairly steep slope at an elevation of 5800 feet with an exposure a little north of east. This tree was felled on July 30 in an east and west direction. Most of the tree was infested with a good brood of D.brevicomis except near the top, where Ips emarginatus broods were common.

As soon as the tree was felled 10 square feet of bark was taken from a strip around the trunk at 25 feet from the base and caged in a metal cage at the laboratory. Square-foot samples were also taken from the top, bottom, north and south sides of the log for brood counts.

On August 8, after nine days' exposure, another set of similar bark samples was taken to show the effect of the exposure. There was apparently no leakage from the cage used with this tree, so we can compare the emergence from the large bark samples taken before and after exposure as well as the brood counts from the bark which was shaved up.

The emergence of D.brevicomis was 66.2 per square foot from the bark caged before exposure and 32.0 per square foot from the bark caged after exposure. This indicates a reduction of over 50 per cent as a result of the nine days' exposure. How much of this is due to natural reductions and how much to the exposure cannot be determined.

Seven clerids were collected per square foot from the bark caged before exposure and 4.4 clerids from the bark caged after exposure. This difference does not represent mortality, however, as many of the mature clerids would normally migrate from the log to the ground while the log was being exposed.

The bark counts taken from the different sides show no direct mortality of either D.brevicomis or E.leconteï. This result was to be expected, as the tree was felled in a cool location near the creek on a northeast slope. A marked reduction, however, is shown in the D.brevicomis broods on all sides of the logs.

It is interesting to compare the brood reductions on the different sides of this tree with those from the other trees. In every case where high temperatures are reached on the upper sides of the log, the reductions are the highest on the upper sides. In the case of this tree, whose upper sides did not reach temperatures high enough to cause direct killing of the broods, the greatest brood reduction occurred on the bottom and north side. The brood reduction on the top and south side was respectively 30 and 40 per cent, whereas the brood reduction on the bottom and north side amounted to 58 and 65 per cent respectively. Evidently in a cool location the principal mortality is due to low temperatures and unfavorable moisture conditions.

Tree M 1 - Lassen Creek area

The last tree studied was a large, old, decadent tree situated on the edge of a brushy, rocky flat which sloped gentle toward the northwest. It was 40 inches in diameter and 100 feet in height. When felled, on August 24, it was infested with a fair to light brood of D.brevicomis, mostly pupae and new adults, and buprestid larvae which were very abundant on the southwest side. The felled tree was exposed to direct sunlight during most of the warm part of the day and largely protected from air movement by the brush and reproduction which surrounded it.

Bark samples were caged and the brood counts made on August 24, shortly after the tree was felled, and again eleven days later on Sept.4. Because of the mixture of species on the sides and bottom it is not possible to draw any conclusions except from results from the top side. Here 100 per cent mortality occurred. In the sample counted before exposure 146 living D.brevicomis were found, and in the sample counted after exposure only 23 were found and all of these were dead. There was no sign of emergence.

The high mortality in this case was probably due to lack of air movement and consequent low radiation, as well as to high air temperature and direct sunlight.

The counts from the caged bark (Chart 10) show no reduction in the number of clerids as a result of exposure, as 6.2 per square foot were collected from the bark caged before exposure and 6.3 per square foot from the bark caged after exposure. The counts made from the samples that were shaved up show the usual tendency. On the top the sample taken before exposure had 9 clerids and the sample taken after exposure had only 2 clerids (per square foot). This result was to be expected, for temperatures high enough to kill 100 per cent of the D.brevicomis would probably drive most of the clerids to the sides or bottom of the log. On the bottom the sample taken before exposure had only three clerids, whereas the sample taken after exposure had eight. This indicates a migration of some of the clerids from the top to the bottom during exposure.

The results from the northeast and southwest sides are not significant because of woodpecker work on the northeast and the high percentage of buprestids on the southwest.

The total effect of the exposure on the Lassen Creek tree is partly concealed by interference of outside factors, particularly buprestids and woodpeckers. In spite of this the results are quite satisfactory from the control standpoint, since 100 per cent of the D.brevicomis were killed on the top and roughly 73 per cent for the whole tree, whereas there is no evidence of any loss of clerids.

DISCUSSION AND CONCLUSIONS

It is evident from the nature of this study that it is almost impossible to obtain clean-cut results because of the large number of variables over which we have no control. Probably the most important of these is the variability in broods in adjacent bark samples. Obviously the same sample cannot be used for the counts both before and after exposure. Because of this there are bound to be inconsistencies in results that could be overcome only by studying a large number of trees and large bark areas from each tree. If an experimental control operation could be undertaken it would be possible to obtain sufficient data to make a more definite estimate of the effect of exposure.

However, in spite of the apparent inconsistencies, there are a few points that stand out quite definitely as a result of the studies of 1928 and 1929. The most important of these are:

1. Bark temperatures fatal to advanced broods of D.brevicomis are reached in the unpeeled bark of logs exposed to direct sunlight on moderately level or southerly slopes when air temperatures over 90° Fahr. are reached.

2. No evidence of mortality among the clerids was found even where the highest bark temperatures were reached. Since living clerid larvae were found in bark in which 100% of the D.brevicomis were killed, it is believed that clerid larvae are not only able to escape from unfavorable conditions but are also able to withstand temperatures which are fatal to D.brevicomis.

3. The mortality on the sides and bottom of the exposed logs is usually higher than for standing infested trees, probably because of less favorable temperature and moisture conditions and the concentration of clerids which are driven from the top of the logs to the sides and bottom.

The fact that D.brevicomis broods may be killed by exposure of the infested logs without apparent injury to the clerids provides a basis for effective control by biological means. But the limitations of this method should be recognized. In the first place, the principal difference between this and the burning method is that the predators are protected instead of destroyed; consequently it would be worth while only when the clerids are abundant enough to be a factor of some importance. In studies covering a period of years it has been found that there is a concentration of clerids on the first, summer-generation trees, and that an average of at least 12 clerids per square foot of infested bark area may be expected on most normally infested trees of this generation. In some trees the average is a little lower, but in many trees as many as 20 or 30 per square foot has been found. Since each clerid is capable of destroying at least 15 or 20 D.brevicomis during the flight period alone, it is believed that this method of control would be more effective than the burning method on summer-generation trees, even though the emergence of D.brevicomis were reduced by the exposure method only 25 per cent below normal.

It is evident that the method would be effective only in fairly open stands and on moderately level or southerly slopes where the bark temperature on the tops of exposed logs would reach well over 100° F.

Since the mortality of D.brevicomis on the tops of favorably exposed logs is quite high, it would probably pay to turn the logs half around after a few days' exposure, so that the side which was on the bottom during the first exposure would be on the top during the second period. In this way a high percentage of the beetles on two sides of the log would be killed by high temperatures, and the concentration of clerids on the other two sides would probably result in a very low emergence of D.brevicomis from the log as a whole. This method will be tested in 1930.

SUGGESTIONS FOR FURTHER STUDIES

Although we have arrived at some fairly definite conclusions as a result of our studies to date, a number of points should be worked out before we shall be in a position to make definite recommendations for the general use of this method:

1. The effect of turning the logs once during the period of exposure. Theoretically at least a very effective control would result from this method, and it should be tested and the results compared with those from logs which are not turned.

2. The effect of exposure on broods in different stages of development. Studies to date have been concentrated on trees with well-advanced broods because it is in this stage that the trees are most easily spotted. However, it would be interesting and of value to determine the effect of exposure on broods in an earlier stage of development.

3. More data should be secured on the effects of exposures of different duration, probably from one day to three weeks.

4. Although we have some data on the effect of slope and exposure on mortality, this part of the study could also be profitably extended.

5. More work should be done toward improving the methods used in determining the results of the exposures, since this is the weakest point in the whole study. So far we have used two methods for determining the effect of the exposures, viz., (1) by caging fairly large areas of bark from the same felled tree before and after exposure, and (2) by making a brood analysis of small samples of bark by carefully shaving the bark and noting the contents, also both before and after exposure. The accuracy of both these methods will be improved as far as possible and another method will also be tried.

The new method requires that the trees used be located in groups, with two or more trees in each group of the same size, with bark of the same thickness and breed of about the same abundance and in the same stage of development. Then one of the two similar trees is felled and trimmed and the log, or logs, exposed for a certain length of time or until all emergence is completed. The other tree would be left standing until emergence is complete. Then by comparing the emergence from the two trees, the one felled and exposed with the one left standing, we could determine the effectiveness of the exposure on the breeds of D.brevicomis. Since we have already shown that the clerids are not adversely affected by exposure, it would not be necessary to check the effect on the clerids. A few sample counts would be made to determine the abundance of both D.brevicomis and the clerids at different times before and during the exposure.

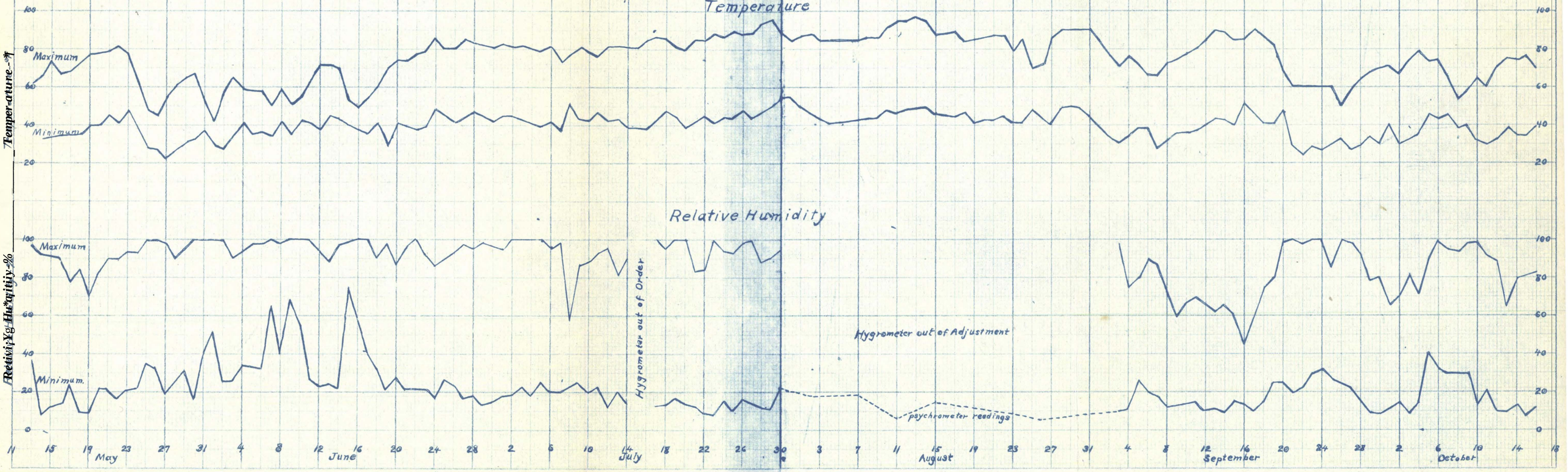
It has already been suggested that the best way of giving this method of control a test would be to use it on some small control operation on an area with a reasonable degree of isolation. Timber Mountain, on the Modoc National Forest, is proposed as a suitable area for such an experiment because it has a fair degree of isolation, is of about the right size, and is conveniently located with respect to our proposed center of work at Mackmore.

It is planned to make a preliminary survey of this area in 1938 to determine more definitely the size of the timbered area, the amount of infestation on the area and its status, and the degree of isolation from other infested timber.

Plate I

Climatological Data

Temperature



Relative Humidity

CHICAGO NEW YORK NO. 346 B

Chart 1.

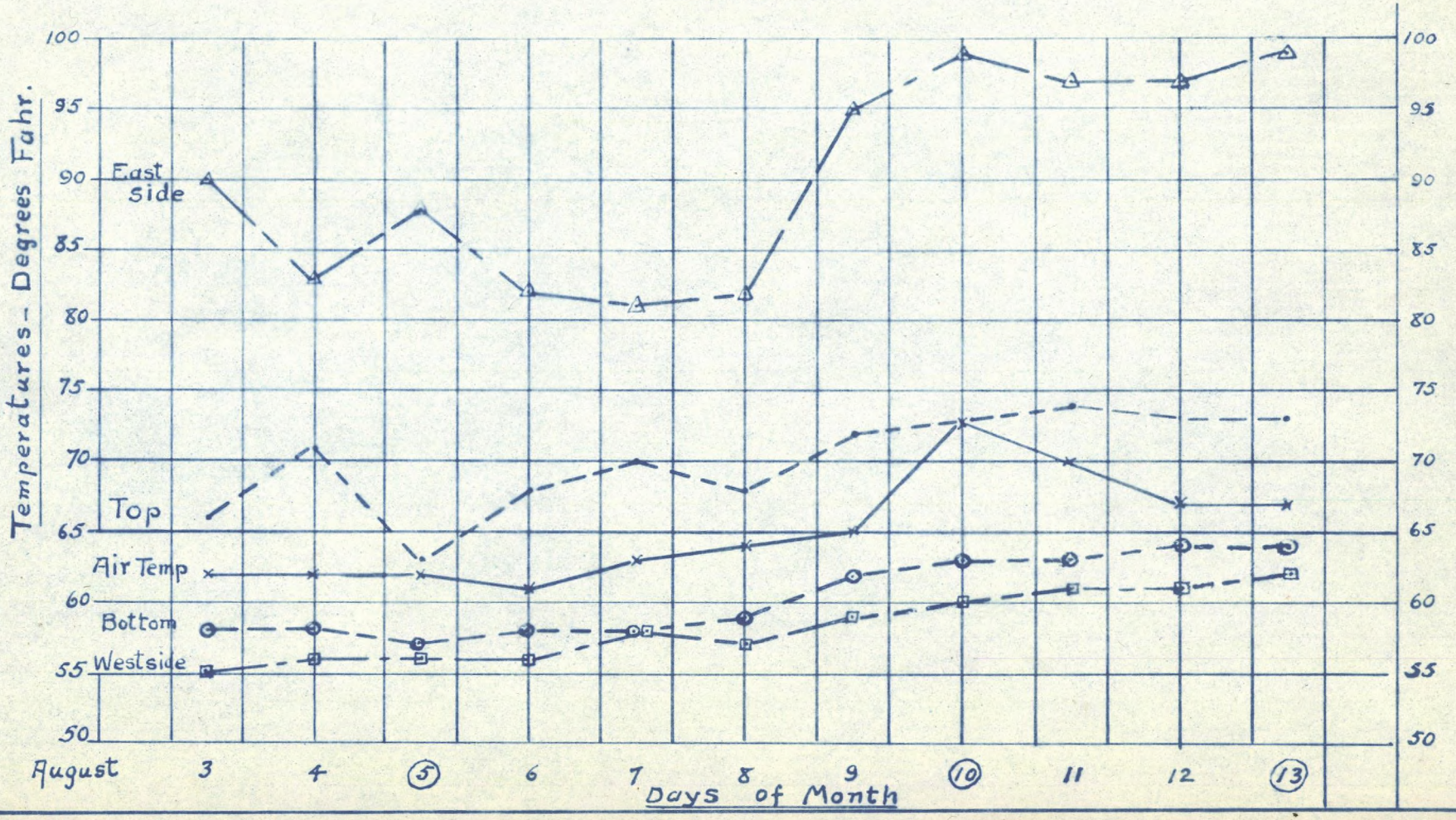
Bark Temperatures

Different Positions on an Infested log

compared with Air Temperature at 8:00 A.M.

Log lying on ground

North And South.



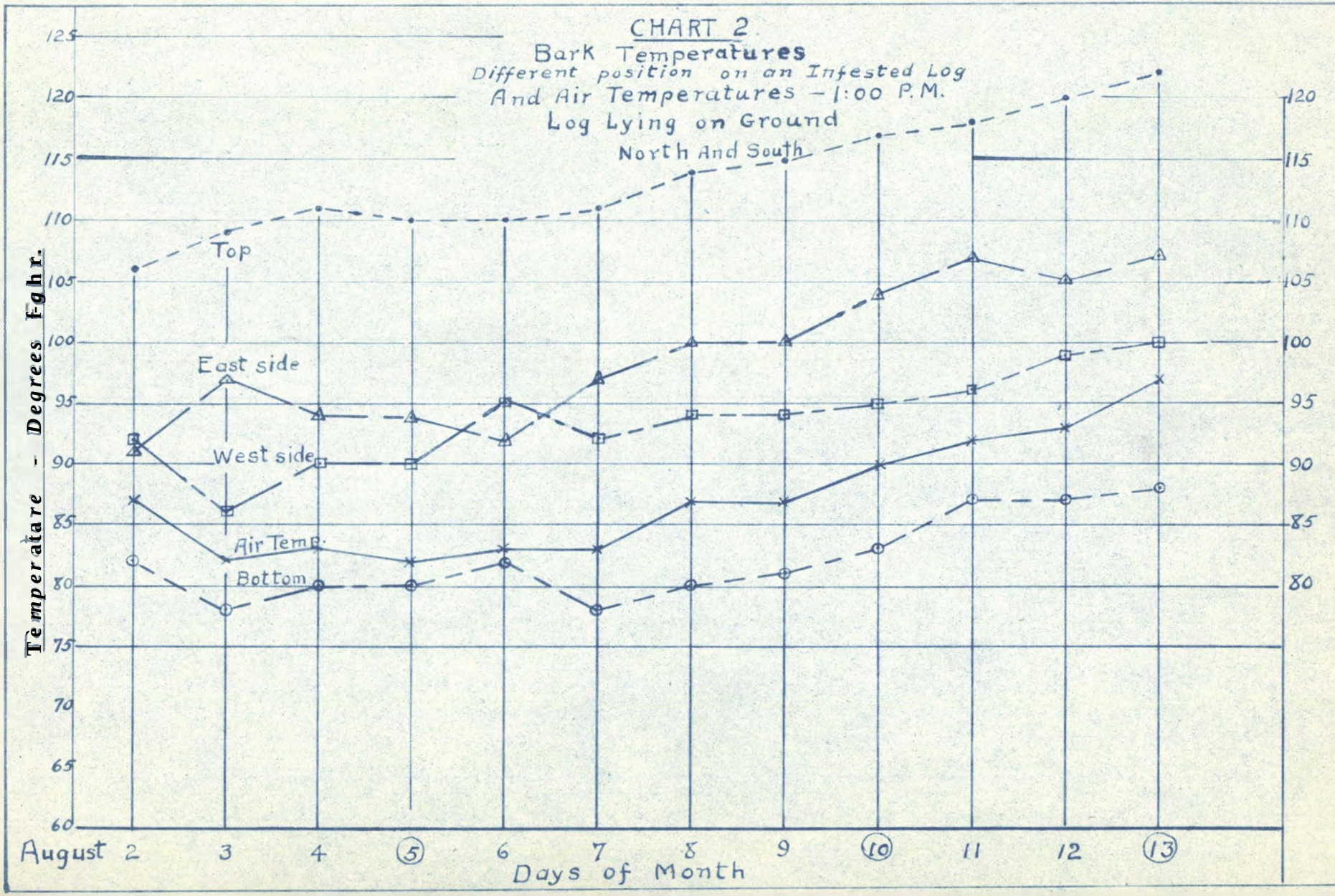


CHART 2
Bark Temperatures
Different position on an Infested Log
And Air Temperatures – 1:00 P.M.
Log Lying on Ground
North And South
Top
East side
West side
Air Temp.
Bottom
Temperature - Degrees Fahr.
125
120
115
110
105
100
95
90
85
80
75
70
65
60
August 2 3 4 (5) 6 7 8 9 (10) 11 12 (13)
Days of Month

Chart 3.

Bark Temperatures Different Position on an Infested Log Compared With Air Temp.

At 5:00 P.M.

Log Lying on Ground

North and South

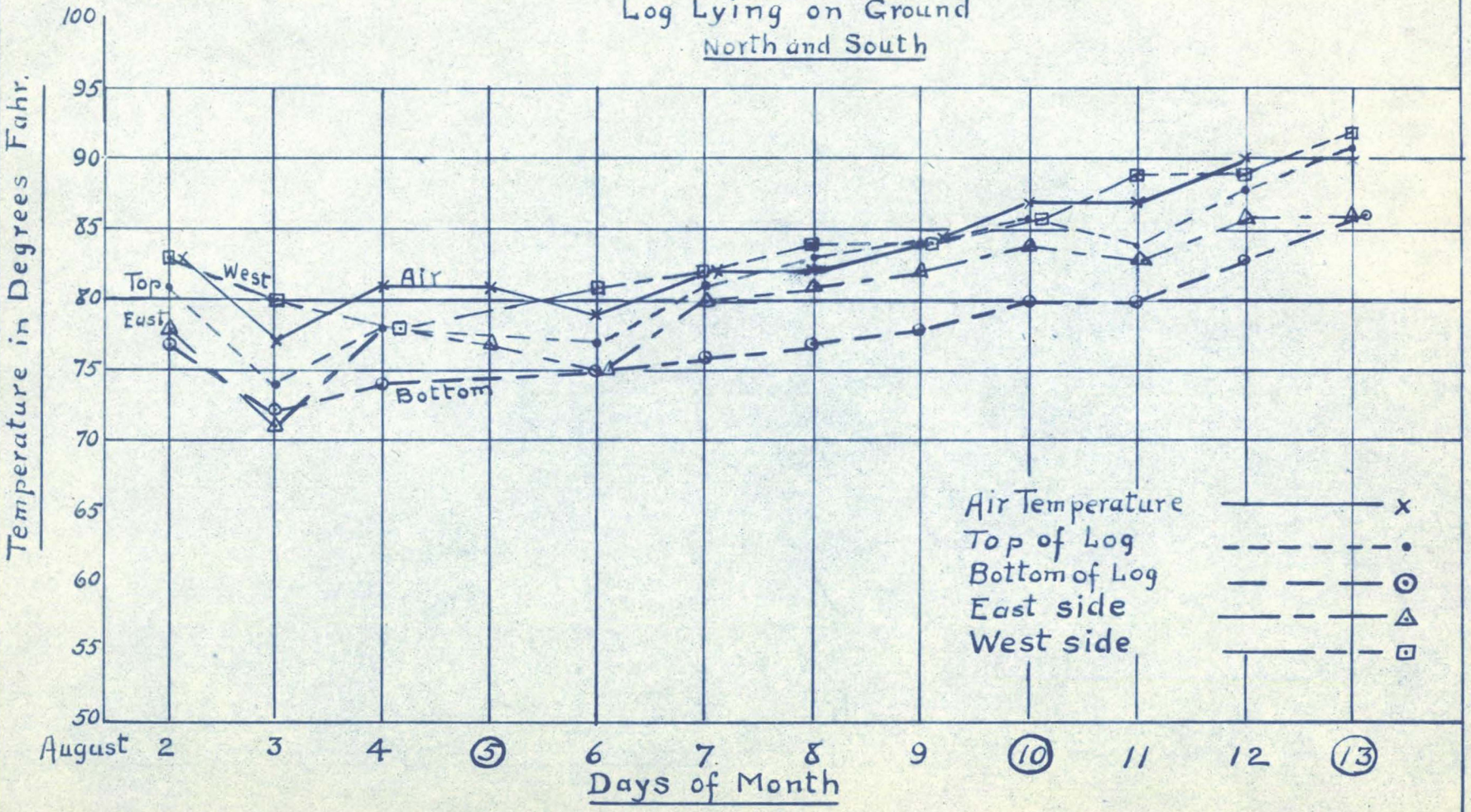
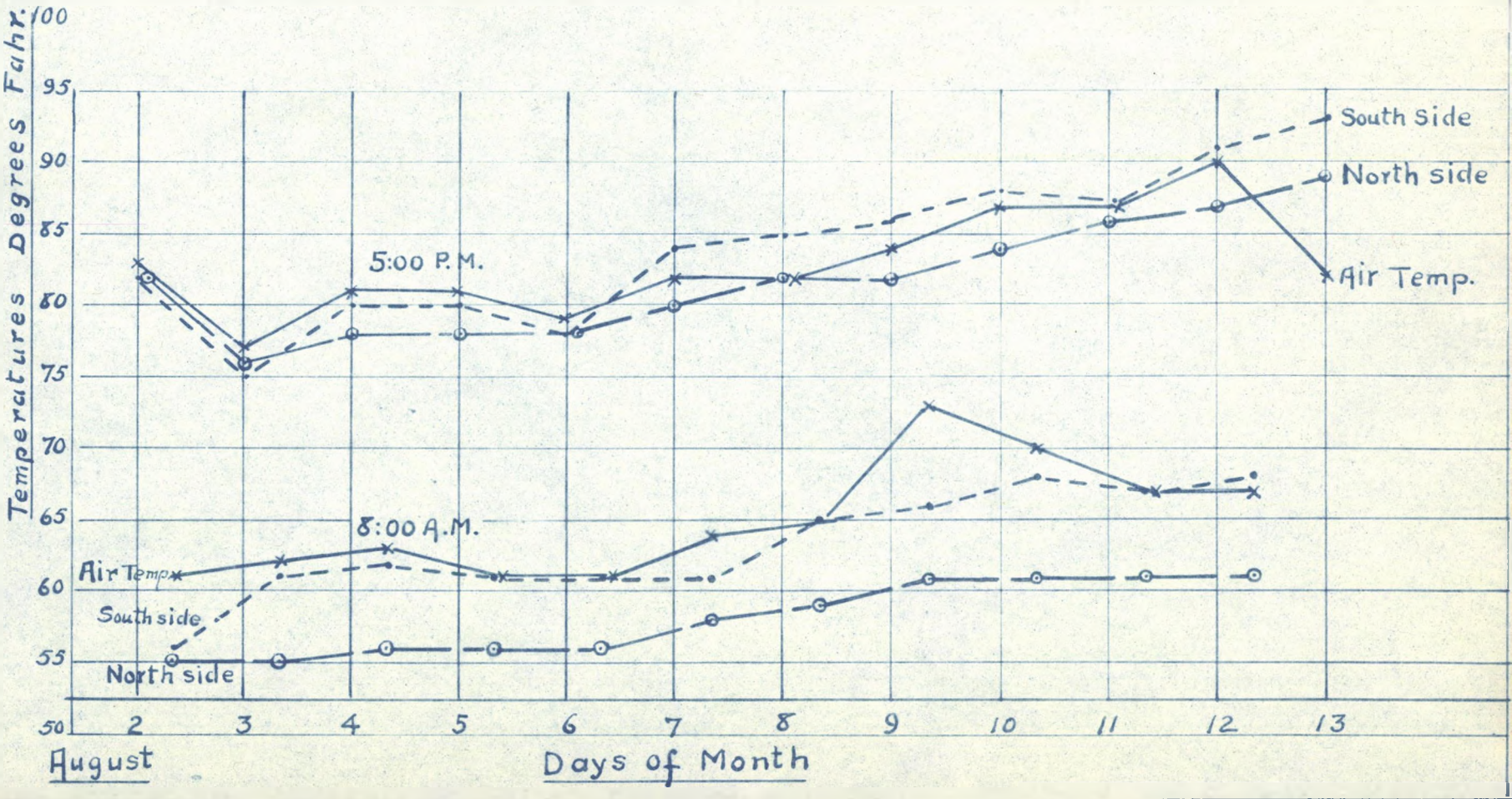


Chart 4

Bark Temperatures of Standing Log
Compared with Air Temperatures
8:00 A.M. and 5:00 P.M.
Infested with D. brevicomis



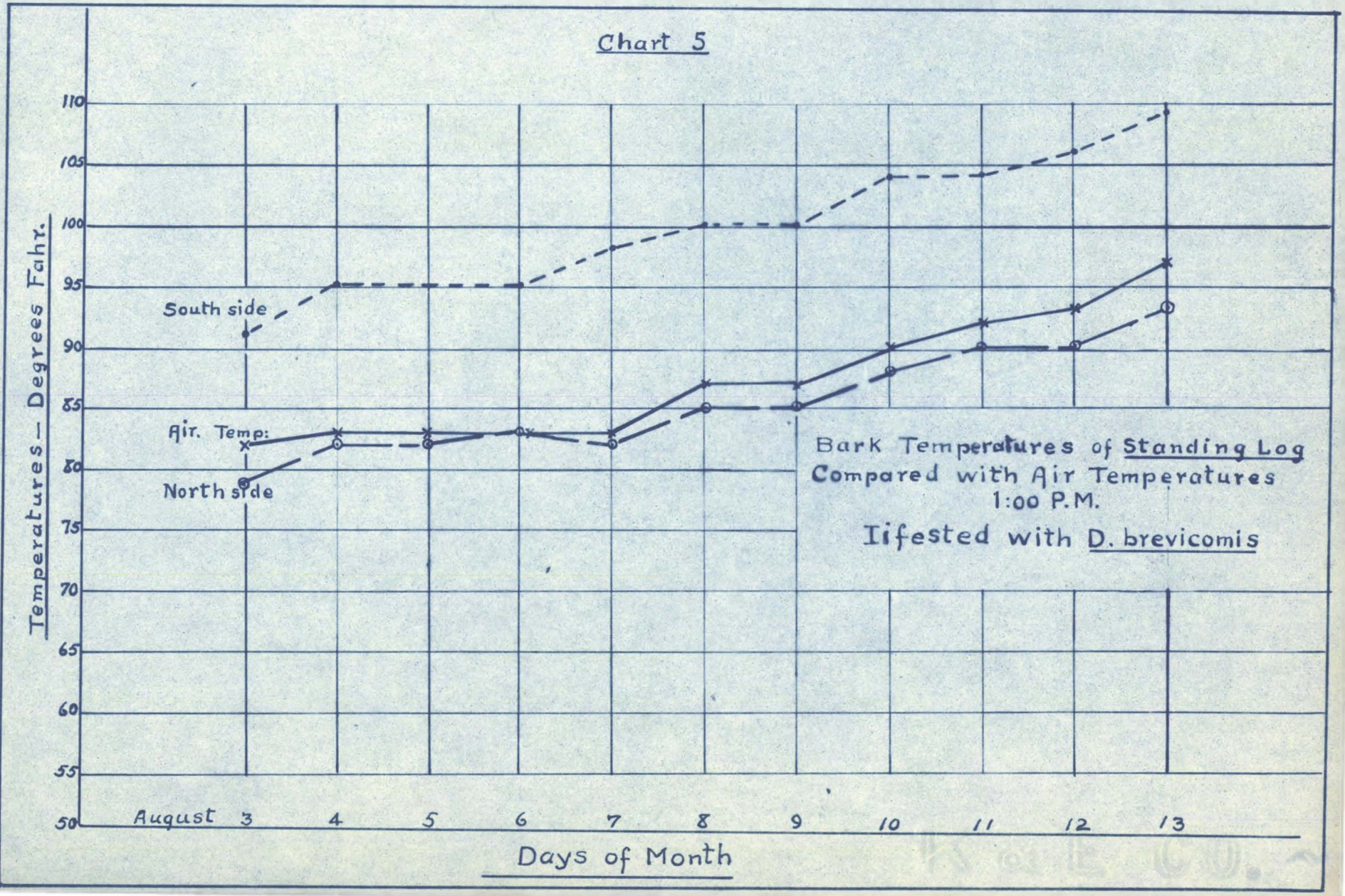


Chart 5
110
105
100
95
90
85
80
75
70
65
60
55
50
Temperatures — Degrees Fahr.
South side
Air. Temp:
North side
Bark Temperatures of Standing Log
Compared with Air Temperatures
1:00 P.M.
Iifested with D. brevicomis
August 3 4 5 6 7 8 9 10 11 12 13
Days of Month

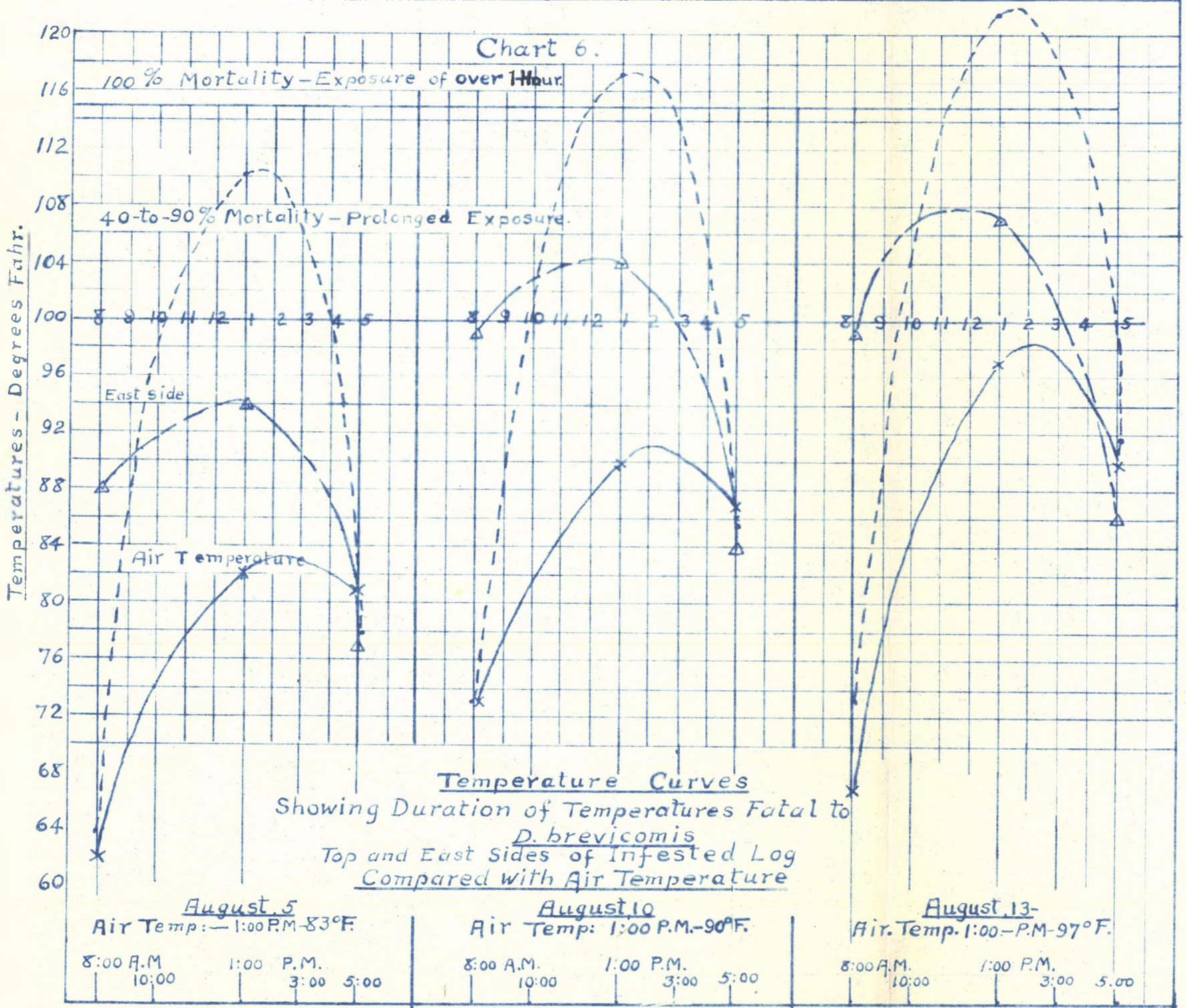


Chart 6.
100 % Mortality – Exposure of over 1 Hour.
40-to-90 % Mortality – Prolonged Exposure.
Temperatures – Degrees Fahr.
120
116
112
108
104
100
96
92
88
84
80
76
72
68
64
60
8 9 10 11 12 1 2 3 4 5
East side
Air Temperature
Temperature Curves
Showing Duration of Temperatures Fatal to
D. brevicomis
Top and East Sides of Infested Log
Compared with Air Temperature
August 5
Air Temp:— 1:00 P.M-83°F.
August 10
Air Temp: 1:00 P.M.-90°F.
August 13-
Air. Temp. 1:00-P.M-97°F.
8:00 A.M
10:00
1:00 P.M.
3:00
5:00

Chart 7

Bark Temperatures
Different Positions on a Green Log
Compared with Air Temp. at 1:00 P.M.
Lying on Ground
North and South

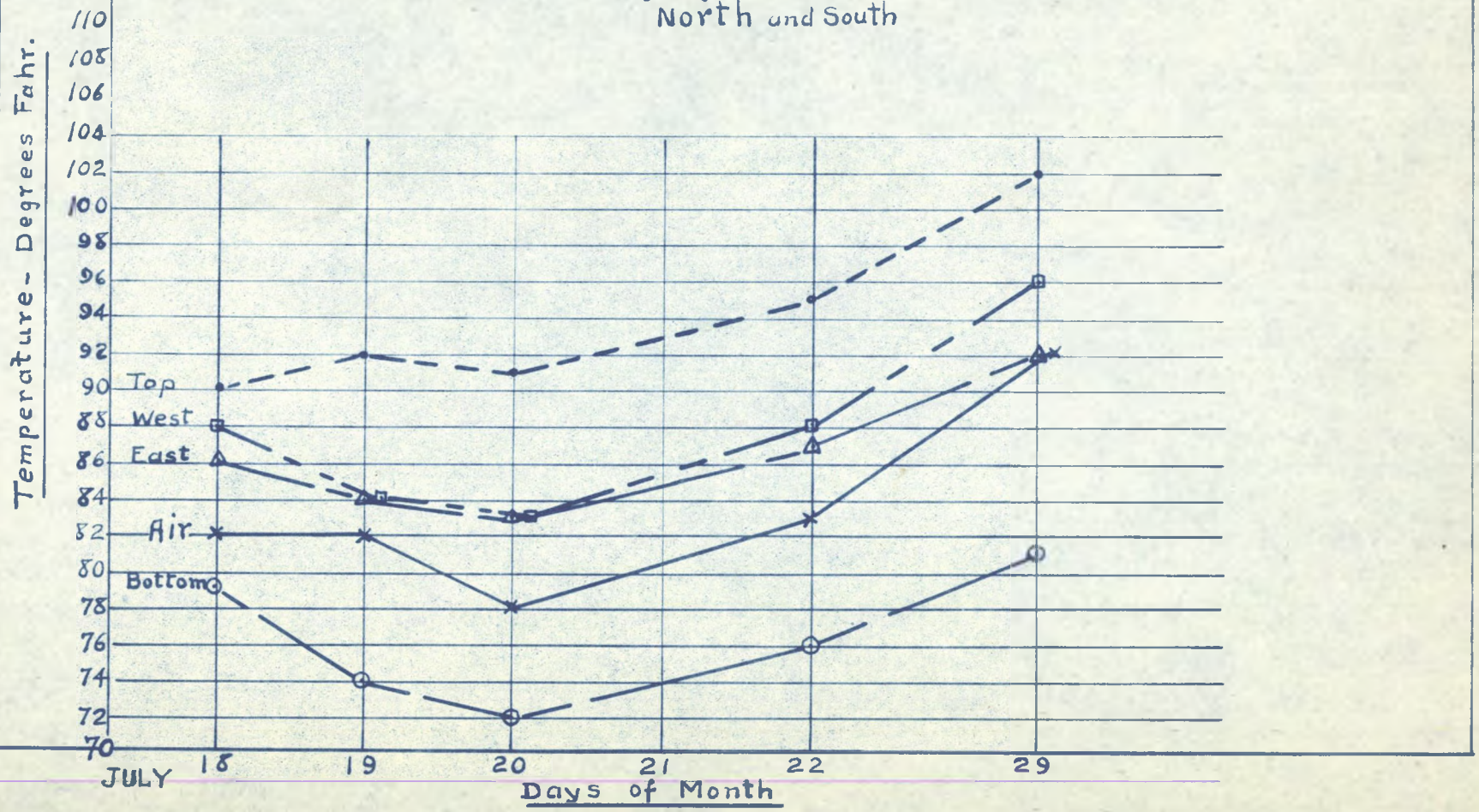


Chart 8

Comparison of Broods of D.brevicomis and E.leconteI - before and after Exposure1

		Top				Bottom				East				West			
		Larv.	Pup.	New Ads.	Total Brood	Lar.	Pup.	New Ads	Total Brood	Lar.	Pup.	New Ads	Total Brood	Lar	Pup.	New Ads	Total Brood
D.brevicomis	Attacks		17				19				15				14		
per sq.ft.	Living	70	165	4	239	75	104	0	179	80	130	0	210	35	102	0	137
Before Exp.	Dead	--	--	--	--	--	--	-	--	--	--	-	--	-	--	-	--
	Attacks		15				17				24				15		
	Living	11	10	0	21	14	45	2	61	23	38	0	61	35	37	9	81
After Exp.	Dead	43	17	3	63	2	3	0	5	8	11	0	19	2	0	0	2
	Total	54	27	3	84	16	48	2	66	31	49	0	80	37	37	9	83
	Mort.in%	79.5	63.0	100.0	75.0	12.5	6.2	0	7.6	25.8	22.5	0	24.0	5.4	0	0	2.4
		Larvae				Larvae				Larvae				Larvae			
E. leconteI		Cgd.	Bark	Bark Cts.		Cgd.	Bark	Bark Cts.		Cgd.	Bark	Bark Cts.		Cgd.	Bark	Bark Cts.	
per sq.ft.	Living	8[2]		17		8[2]		6		8[2]		4		8[2]		6	
Before Exp.	Dead	0		0				0				0				0	
	Living	5		4		9		3		4		1		9		2	
After Exp.	Dead	0		0		0		0		0		0		0		0	
	Total	5		4		9		3		4		1		9		2	
	Mort.	0		0		0		0		0		0		0		0	

Note[1] - From Log M 1, Brown's Well, used in Temp. Study

[2] - Av. for 10 sq.ft. from strip around log

Chart 9

Summary of Biological Control Data - 1929

		D.brevicomis				R.lecontei (all living)				Remarks
		Before Exp: Brood Cts.	After Exposure			Before Exp.		After Exp.		
		Living	Liv.	Dead	Living	Caged Bark	Brood Counts	Caged Bark	Brood Counts	Felled Aug. 1
Tree M 3 - B.M.	Top	239	21	63	25	Av for	17	5	4	Brood when
Temp. Study Tree	Bottom	179	61	5	71	10sqft	6	9	3	felled mostly
Exp. 12 days	West	210	91	2	74		4	4	1	larvae and pupae
at Buck Creek	East	139	61	19	65		6	9	2	Full sunlight,
	Av.	191	56		59	8	8	7		gentle west slope
	Top	129	20	48			5		6	Felled July 27
Tree M 1 - G.M.	Bottom	100%	Ips & Bup				-		-	Exp. 7/27 to 8/3
Felled and exp.	West	58	38	0	rt. Ips and Bup		0		3	Brood - D.b. pupae
nr. Crom's Mill	East	24	12	0	" " "		3		0	and new adults
	Av.	70	25			3.2	2.0	2.3	3	Light shade
	Top	123	55				0		3	Felled July 30
Tree M 3 - B.C.	Bottom	183	76				1		8	Exp. 7/30 - 8/8
Felled and exp.	North	434	83				2		2	Brood - large larvae
nr. Buck Creek	South	127	77				4		6	Exposure - N.E.
	Av.	167	81			7	1.7	4.4	5	medium steep
	Top	146	0	23			9		2	Felled Aug. 24
Tree M 1 - L.C.	Bottom	49	71				3		8	Exposed 8/24 - 9/4
Felled and exp.	S.W.	30	3				0		0	Brood - large larvae,
nr. Lassen Creek	N.E.	157	28				15		3	pupae, new adults
	Av.	93	26			6.2	7	6.3	3	Full sunlight

Chart 10

Brood Analysis of Certain Trees
Before and After Exposure[1]

Tree No.	Treatment	Position	Attacks	D. brevicomis Larvae Liv	Larvae Dead	Pupae Liv	Pupae Dead	New Ads. Liv	New Ads. Dead	Totals Liv	Totals Dead	T. lecontei Living	T.V.c.[2] Living	Remarks
		Top	22	17		82		50		129		3	5	
	Before	Bottom	1	—		—		—		—		0	0	100% Ips sp.
														arginatus
	Exposure	East	20	17		55		6		58		3	3	
W 1 - C.M.		West	9	0		15		9		24		0	0	
Crom's Mill		Top	10	0	2	4	22	16	24	20	48	6	6	
Area	Exposed 7 ds.	Bottom	—	—	—	—	—	—	—	—	—	-	-	100% Ips sp.
														arginatus
	75% sun	East	14	0	0	27	0	11	0	38	0	3	2	
		West	6	0	0	5	0	9	0	13	0	0	2	
		Top	10	68		59		8		125		0	2	
	Before	Bottom	15	110		73		0		183		1	2	
	Exposure	North	14	215		16		3		234		2	1	
W 3 - B.C.		South	17	75		52		0		127		4	2	
Buck Creek		Top	14	17		52		19		88		5	1	
Area	Exposed 9 ds.	Bottom	20	5		53		40		76		8	1	
	N.E. Exposure	North	16	23		38		22		83		2	0	
		South	12	9		32		36		77		6	1	
		Top	7	16		73		57		146		9	3	
	Before	Bottom	11	3		12		34		49		3	2	
	Exposure	S.	5	20		0		0		20		0	0	Mostly Dupr.
W 1 - L.C.		N.E.	9	4		43		110		157		15	2	
Lassen Cr.		Top	7	0	6	0	17	0	0	0	23	2	3	10% woodpkr.
Area	Exposed 11 ds	Bottom	11(sm.33)	6	0	11	—	16		71	0	8	2	
	Full sunlight	S.W.	2	—	—	3	—	—	—	5	0	0	1	Mostly Dupr.
		N.E.	9(sm.18)	—	—	2	0	8	—	28	0	3	3	30 woodpkrs.

[1] Brood counts from shaved-up bark

[2] T.V.c. - Temnochila virescens Febr. var. chlorodia (Mann.), a general predator